

Development of High-Performance Lithium-Ion Cell Technology for Electric Vehicle Applications

P. I. Keith Kepler
Farasis Energy
June, 20th 2018

Project ID # bat355

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Program Overview

Timeline

- Project Start Date: Feb. 2017
- Project End Date: Sep. 2019
- Percent complete : 22%

Budget

- \$5.9M
- 50%/50% USABC/Farasis
- Subcontractors
- LBNL \$300K
- ANL \$400K

Barriers

- Achieving high energy density with stable chemistry to meet cycle life and calendar life goals.
- Meeting the cost target of ~ \$0.10/Wh
- Manufacturing processes compatible with new materials

Partners

- BASF
- 3M/OneD material/Shin-Etsu/XG Science
- Argonne National Lab
- Lawrence Berkley Lab
- Solvay/ Daikin
- Entek/Celegrad



Relevance/Project Objectives

- Project Objective

- Develop a EV cell technology capable of providing 350 Wh/kg after 1000 cycles at a cost target of \$0.10/Wh.
- To achieve this the BOL cell energy density target will be ~ 400Wh/Kg.

| GAP CHART | | Cell level | | | | |
|--|--------|--|---------------------|--------------------------------------|--|--|
| End of life characteristics @ 30 degC | Units | Baseline 29Ah (BOL) | Interim Cells (BOL) | Final Cells (BOL) | USABC Goal (EOL) | Final Cells (EOL) |
| Peak discharge power density, 30 s pulse | W/L | 4038 | 1750 | 2160 | 1500 | 1728 |
| Peak specific discharge power, 30 s pulse | W/kg | 1848 | 750 | 905 | 700 | 724 |
| Peak specific regen power, 10 s pulse | W/kg | 585 | 300 | 378 | 300 | 302 |
| Available energy density @ C/3 discharge rate | Wh/L | 470 | 725 | 947 | 750 | 852 |
| Available specific energy @ C/3 discharge rate | Wh/kg | 215 | 300 | 392 | 350 | 353 |
| Usable energy @C/3 discharge rate | Wh | 104 | TBD | 227 | n/a | 204 |
| Calendar life | Yr | TBD | TBD | 15 | 15 | 15 |
| DST cycle life | Cycles | TBD | 1000 | 1000 | 1000 | 1000 |
| Selling price @ 100k units/annum | \$/kWh | TBD | TBD | 100 | 100 | 100 |
| Operating environment | degC | -30 to +52 | | -30 to +52 | -30 to +52 | -30 to +52 |
| Nominal recharge time | hr | <7, J1772 | | <7, J1772 | <7, J1772 | <7, J1772 |
| High rate charge | min | 80% ΔSOC in 15 min | | 80% ΔSOC in 15 min | 80% ΔSOC in 15 min | 80% ΔSOC in 15 min |
| Maximum operating voltage | V | 4.15 | | 4.5 | N/A | 4.5 |
| Minimum operating voltage | V | 3 | | 2.5 | N/A | 2.5 |
| Peak current, 30 s | A | 160 (3P=480A) | | 150 (3P=450A) | 400 | 150 (3P=450A) |
| Unassisted operating at low temperature | % | >70% available energy @ C/3 @ -20 degC | | >70% useable energy @ C/3 @ -20 degC | >70% available energy @ C/3 @ -20 degC | >70% available energy @ C/3 @ -20 degC |
| Survival temperature range, 24 hr | degC | -40 to 66 | | -40 to 66 | -40 to 66 | -40 to 66 |
| Maximum self-discharge | %/mo | <1 | | <1 | <1 | <1 |



Relevance/Project Objectives

- Project Technical Target
 - Year 1: Baseline deliverable (220Wh/Kg)
 - Year 2: Gen1 Deliverable (300Wh/Kg)
 - Year 3: Gen2 Deliverable (375-400Wh/Kg)
- Cell Component R&D
 - Develop stable high capacity anode and cathode materials and electrode
 - Develop cost effective and manufacturable pre-lithiation technology based on sacrificial cathode additives.
 - Develop and optimize high voltage, high conductivity and high voltage safety electrolytes
- Risk
 - There are multiple interacting failure mechanisms at the materials and cell level that are barriers to achieving the system level battery performance goals.
 - Manufacturing processes compatible with new materials



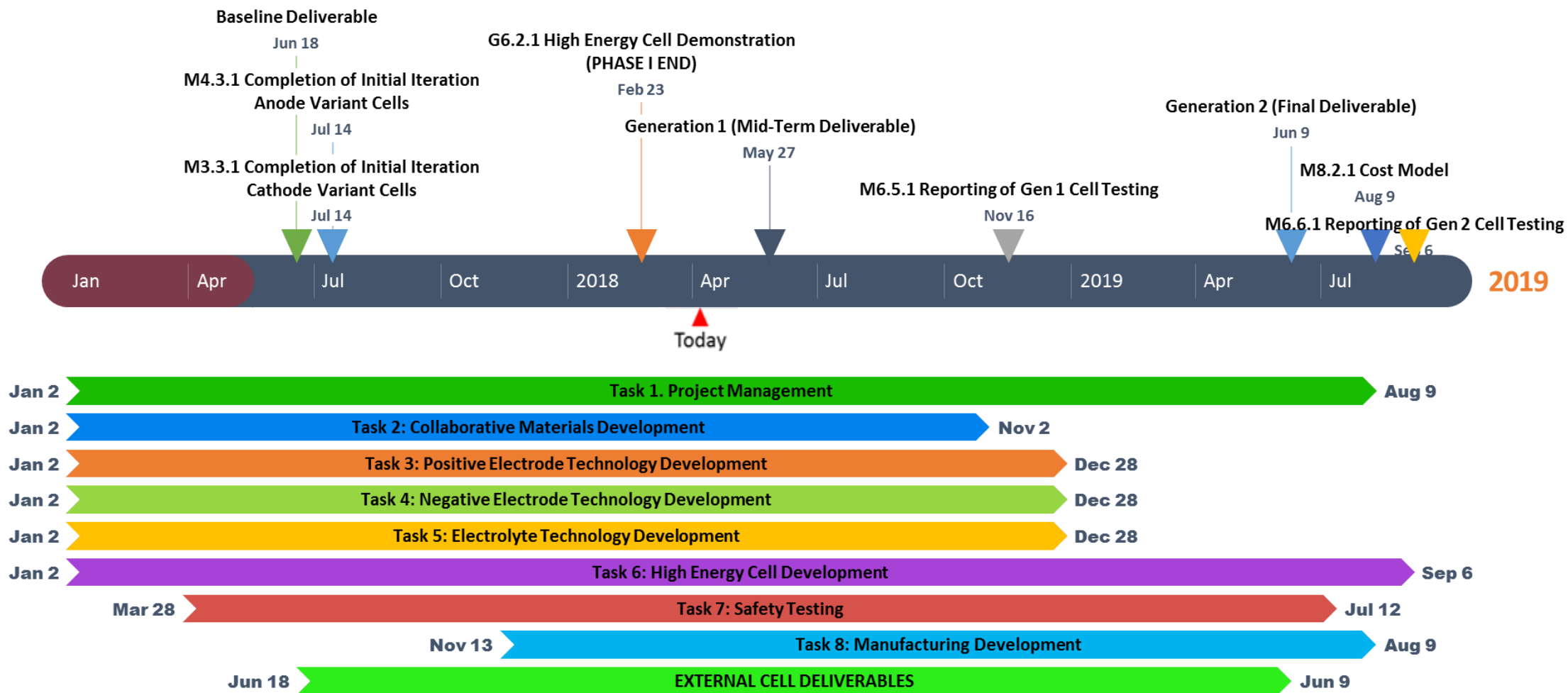
Project Milestones

- The key Milestones are associated with demonstrating progress towards the goals of the project.

| Milestone Summary Table | | | | | | |
|-------------------------|---|--------------------------------------|------------------|--|--------------------------|-------------|
| Task Number | Task Title | Milestone or Go/No-Go Decision Point | Milestone Number | Milestone Description (Go/No-Go Decision Criteria) | Planned Completion Dates | % completed |
| 3.3 | Positive Electrode Developmental Cell Build | Milestone | M3.3.1 | Production of pouch cells representing multiple positive electrode design variants | July, 2017 | Completed |
| 4.3 | Negative Electrode Developmental Cell Build | Milestone | M4.3.1 | Production of pouch cells representing multiple negative electrode design variants | July, 2017 | Completed |
| 6.2 | Ongoing Cell Development | Go/No-go | G6.2.1 | Demonstration of High-Energy Cells exceeding 300 Wh/kg after RPT2 | April, 2018 | Completed |
| 6.5 | Generation 1 Cell Testing | Milestone | M6.5.1 | Completed reporting of performance and safety testing results for Generation 1 cells | January, 2019 | 50% |
| 8.2 | Cost Model Development | Milestone | M8.2.1 | Submission of detailed cost model based on new materials and processes used in Generation 2 cells. | August, 2019 | 0% |
| 6.7 | Generation 2 Cell Testing | Milestone | M6.7.1 | Completed reporting of performance and safety testing results for Generation 2 cells | October, 2019 | 20% |



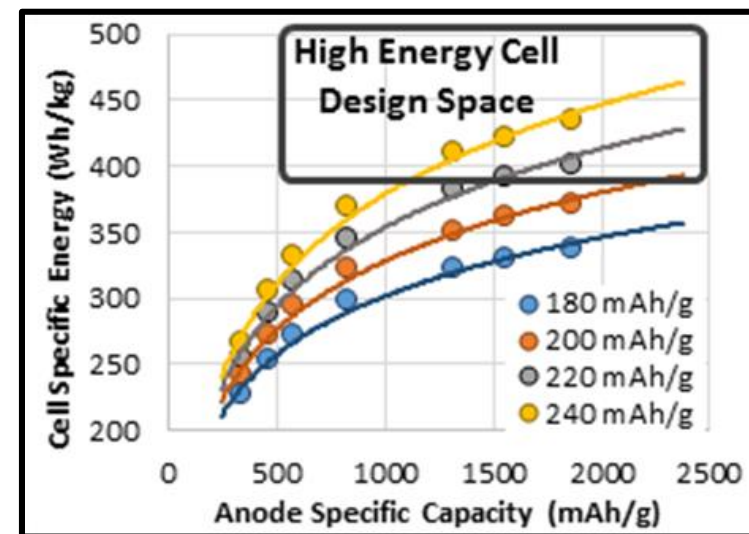
Milestone Timing





Technology Approach

- Development focused on addressing key current barriers to achieving high capacity, long cycle life and safer Li-ion cells
- **Electrode Chemistry:**
 - Stabilized Ni-rich/Mn-rich, High Voltage ($\geq 4.6\text{V}$) Cathode Composites (220-240 mAh/g)
 - Silicon Composites (1200 – 1800 mAh/g)
 - Stabilized Lithium Source Material (LFO – 800 mAh/g)
 - **Contributors:** Argonne National Laboratory, OneD, 3M, Shin-Etsu XG Sciences, BASF, Nanoscale Components
- **Electrolyte Formulation:**
 - Fluorinated solvents
 - Stabilizing additives/salts.
 - Contributors:** DuPont, Daikin, 3M, BASF
- **Electrodes and Cell:**
 - Optimized, high density, composite active material formulations
 - Low reactivity conductive additives
 - Advanced binder formulations
 - Advanced separators: Coatings, high voltage stability
 - Contributors:** Lawrence Berkeley National Laboratory, Entek, Celgard





Strategy - Development Plan

Cell materials development

New materials sourcing and characterization
New materials improvement, synthesis, development (ANL, LBNL)
Form factor: Coin Cells,
Metrics: Capacity, rate, stability

Positive electrode

C1: ~ 11 Materials Variations (~ 320 Wh/Kg)
C2: ~ 3 Materials Variations (shift to 400Wh/kg)
C3 : ~ 2 Materials Variation (Target ~ 400Wh/Kg)
Form Factor: Small Full cells (SLP - <2Ah), fixed anode, electrolyte, energy density
Metrics: Capacity, rate, cycling, safety

Negative electrode

A1: ~ 4 Materials Variations (~ 320Wh/Kg)
A2: ~ 4 Materials Composite Variations (shift to 400Wh/Kg)
A3: ~ 2 Materials Variations (Target ~ 400Wh/Kg)
Form Factor: Small Full cells (SLP - <2Ah), fixed anode, electrolyte, energy density
Metrics: Capacity, rate, cycling, safety

Electrolyte

E1: ~ 10 Materials Variations (~ 320 Wh/Kg)
E2: ~ 5 Materials Variations (~ 320 Wh/Kg)
E3 : ~ 5 Materials Variations (~ 400 Wh/Kg)

Form Factor: 18650, <2Ah pouch, single cell design
Metrics: Capacity, rate, cycling, calendar life, safety

Cell

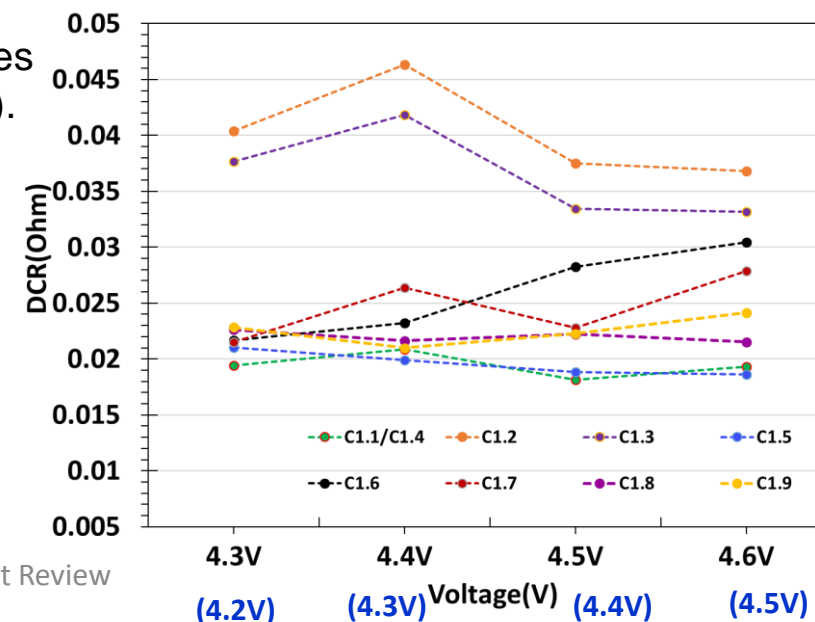
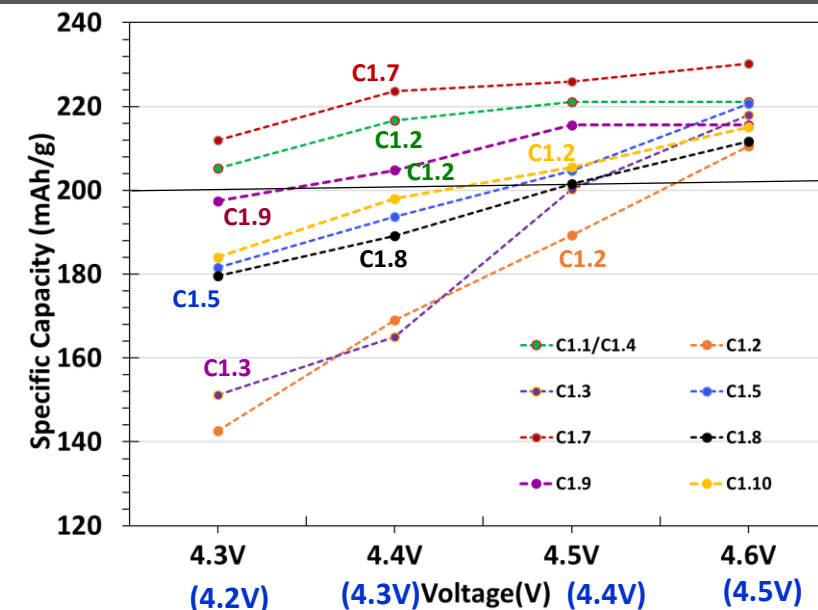
DOE1: ~ C1 & A1 (Optimized formulation for 3 C1 & 2 A1 with 5 E1)
DOE2: ~ C2 & A2 (Optimized formulation for 2 C1 & 2 A1 with 5 E1)
DOE3: ~ 7 Materials Variations
Form Factor: Full cells, fixed anode, electrolyte, energy density
Metrics: Capacity, rate, cycling, safety

Deliverables:
1st Year : Baseline: Baseline (30Ah) NCM/Graphite
2nd Year- Gen1: Gen 1 Cells (10Ah) Chemistry from **DOE 2**
3rd Year and final deliverables - Gen 2: Gen 2 Cells (65Ah) Chemistry from **DOE3**



(C1) Cathode Materials Challenges & Development

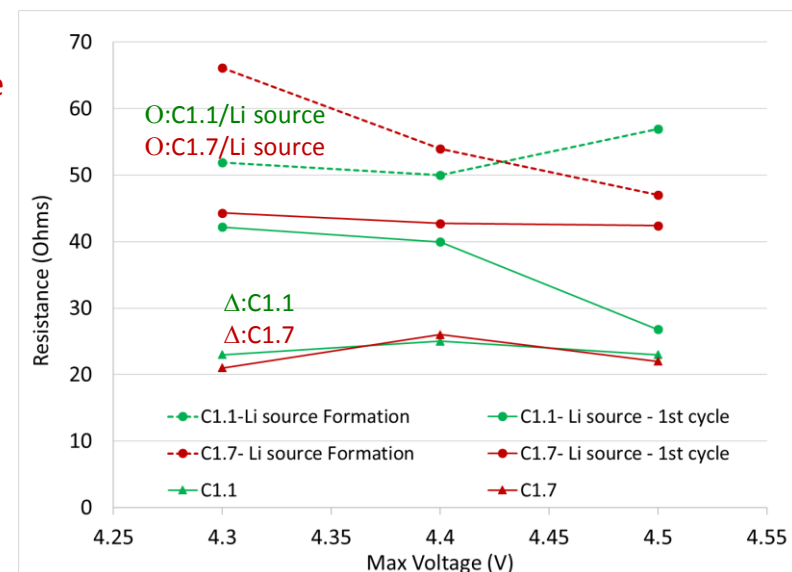
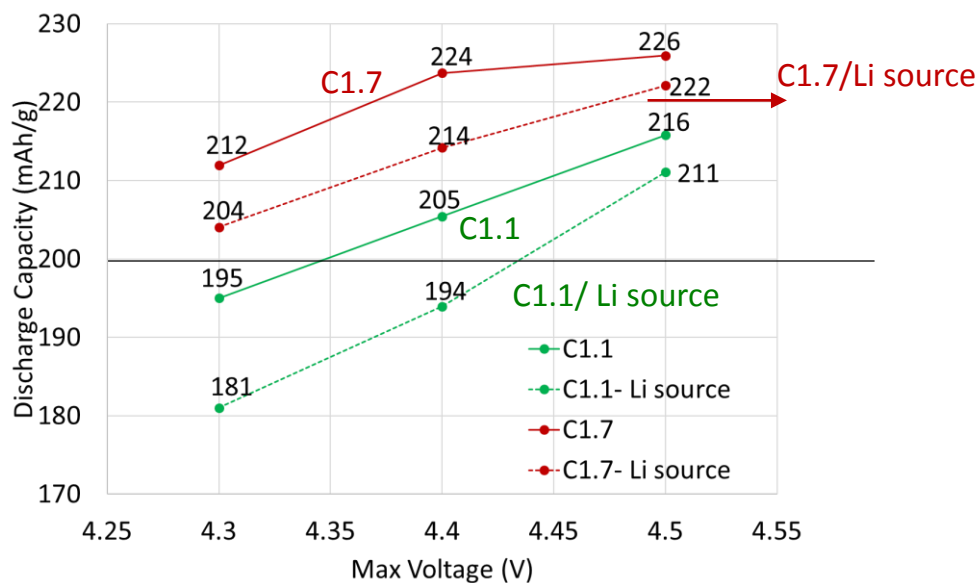
- **C1 Cathode Performance Target:** 200-220 mAh/g, 1000 cycles
- **Development Plan for Cathode Active materials C1:**
 - Development will focus on high Ni-content (NCM, NCA, CAM7..) based cathodes
 - Reversible capacity > 200mAh/g
 - Higher voltage operation
 - Cathode Surface stabilization
 - Stable electrolyte
 - Composites with Layered/Layered Mn-rich materials (HENCMS)
 - Other composite electrode formulations balancing properties of different materials (particles size, reactivity, capacity etc).
- **Barriers:**
 - High specific capacity cathode materials
 - Cycle life
 - Safety





(C2) Development and Incorporation of Li Source

- **C2 Cathode Performance Target:** 200-220 mAh/g, 1000 cycles
- **Development Plan for Cathode Active materials C2:**
 - Development will focus on high Ni-content based cathodes
 - Reversible capacity > 200mAh/g
 - Development and incorporation of Li-Source for Cathode
- **Barriers:**
 - Observed impedance increase of the cell associated with incorporation of Li source
 - Progress on identification of impedance increase mechanisms and development of solutions associated with material stability and processing





Anode Materials Challenges & Development

- **Si Based Anode Advantage:**

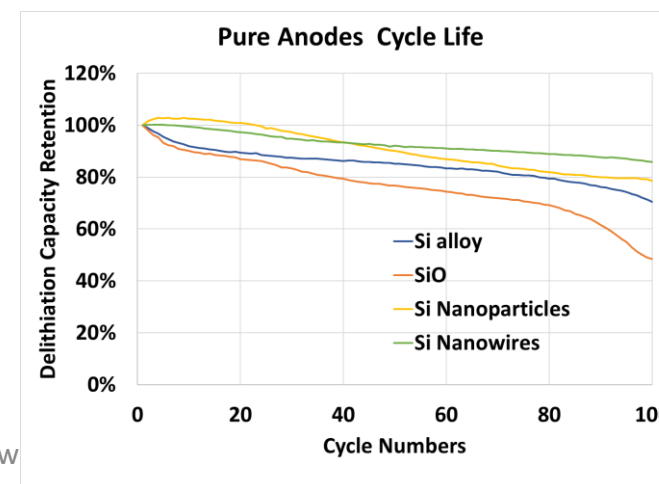
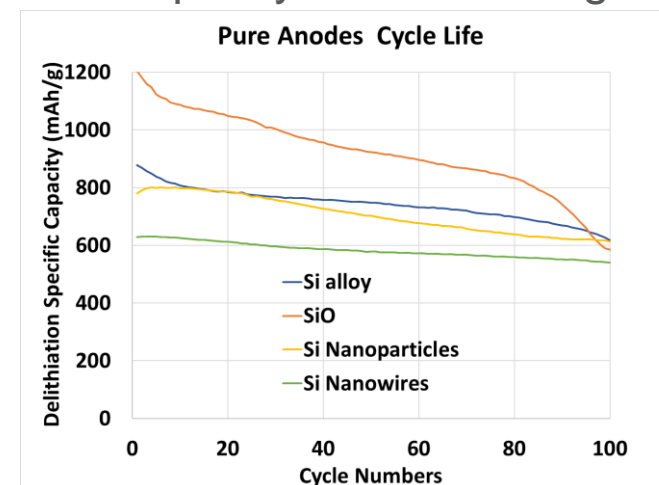
- Si-based anodes are attractive alternatives to graphite because Si can alloy 4.4 Lithium ion per silicon ($\text{Li}_{4.4}\text{Si}$) resulting in an extremely large theoretical capacity of 4200mAh/g versus graphite's 372mAh/g.

- **Challenges with Si Anode**

- Silicon volume expansion
- Lithium consumption due to continual SEI growth
- Irreversible capacity loss
- Phase transition

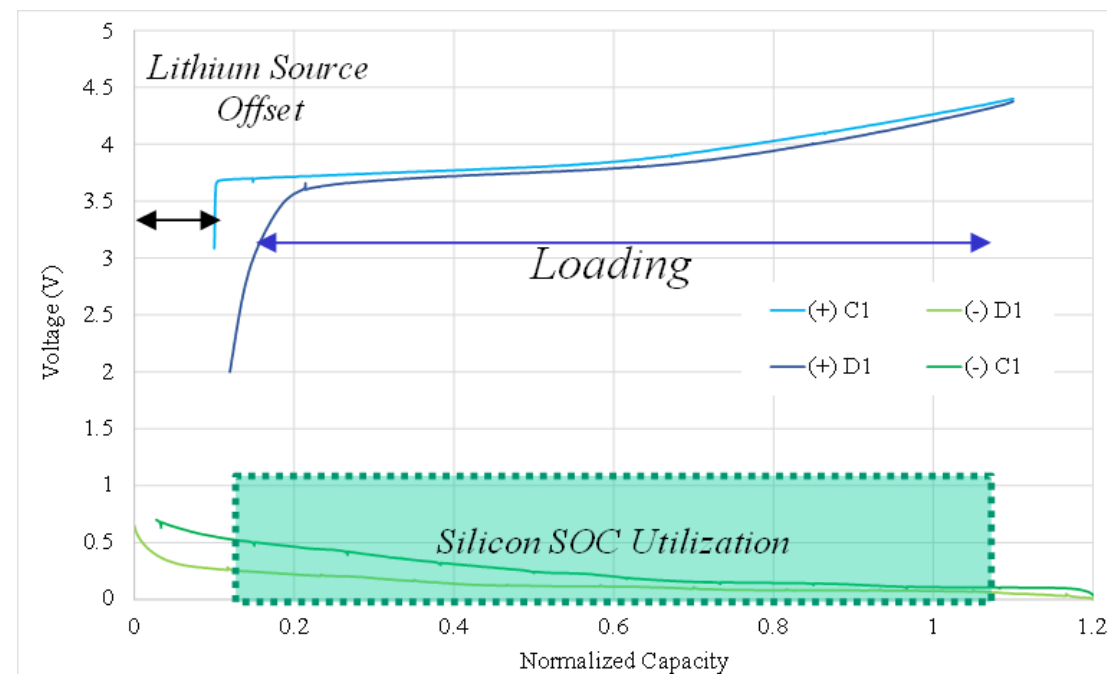
- **Materials Options for Silicon Anodes**

- Silicon Alloys
- SiO
- Si nanowires
- Si nanoparticles



+ Si Utilization Challenges & Development - Cell Design

- To meet the required capacity of 1800mAh/g we have to form composite of different Si materials. To get the maximum utilization of the anode material we have to adjust the percentage of Li source in the cathode to compensate the 1st cycle loss.
- Si loadings and composition as well as the lithium source amount in the cathode are selected to cycle within the desired voltage window to reduce volumetric expansion and other degradation mechanisms associated with Si.
- Having sacrificial Li in the cathode as lithium source will help to achieve the capacity > 1200 by compensating for the high irreversible capacity loss (IRCL) and it is cost effective as compared to other pre-lithiation techniques.



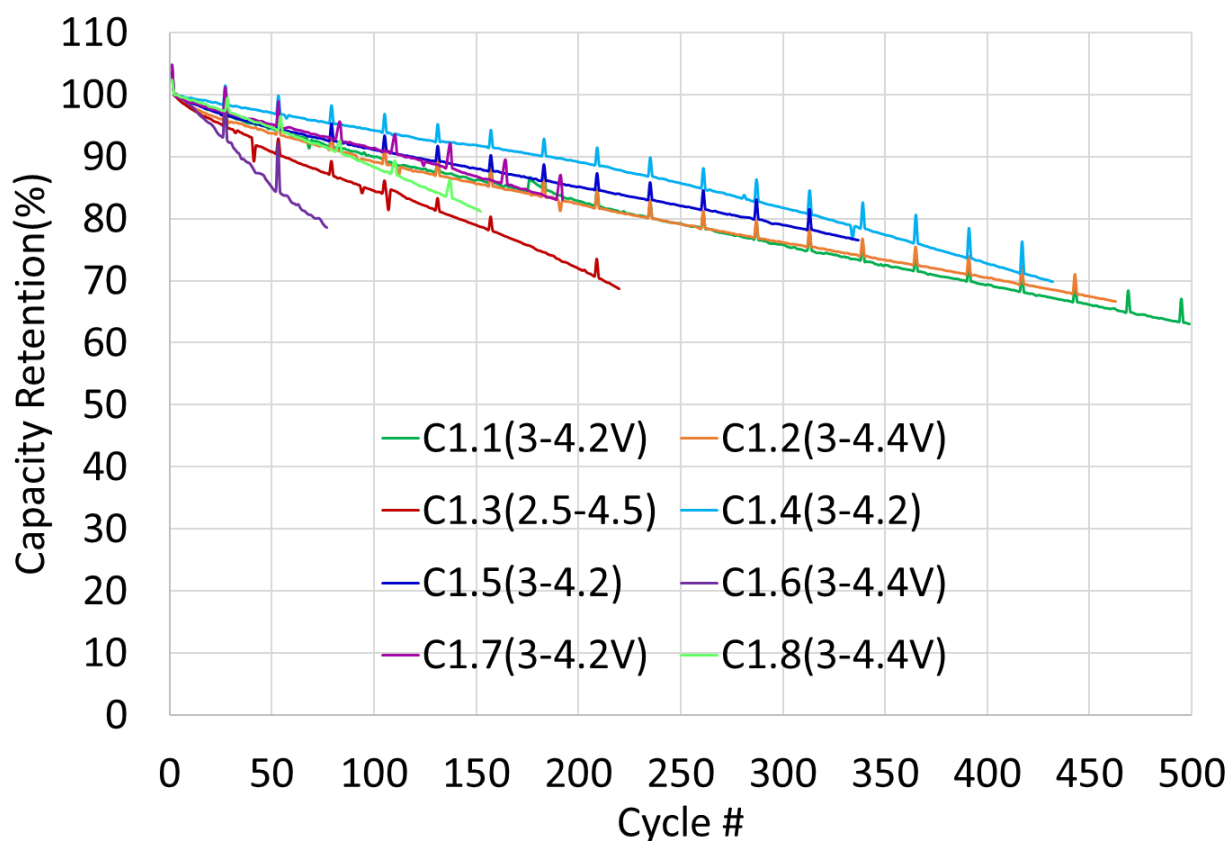


Technical Accomplishments

(C1) Positive Electrode Technology Development

- Evaluated 8 different cathode materials in a single layered pouch cell with a single **anode (A1.1)** at fixed capacity targeting 325-350 Wh/kg in (40-77Ah cell form factor): Cycle life

Cycling: 0.33C/0.5C with A1



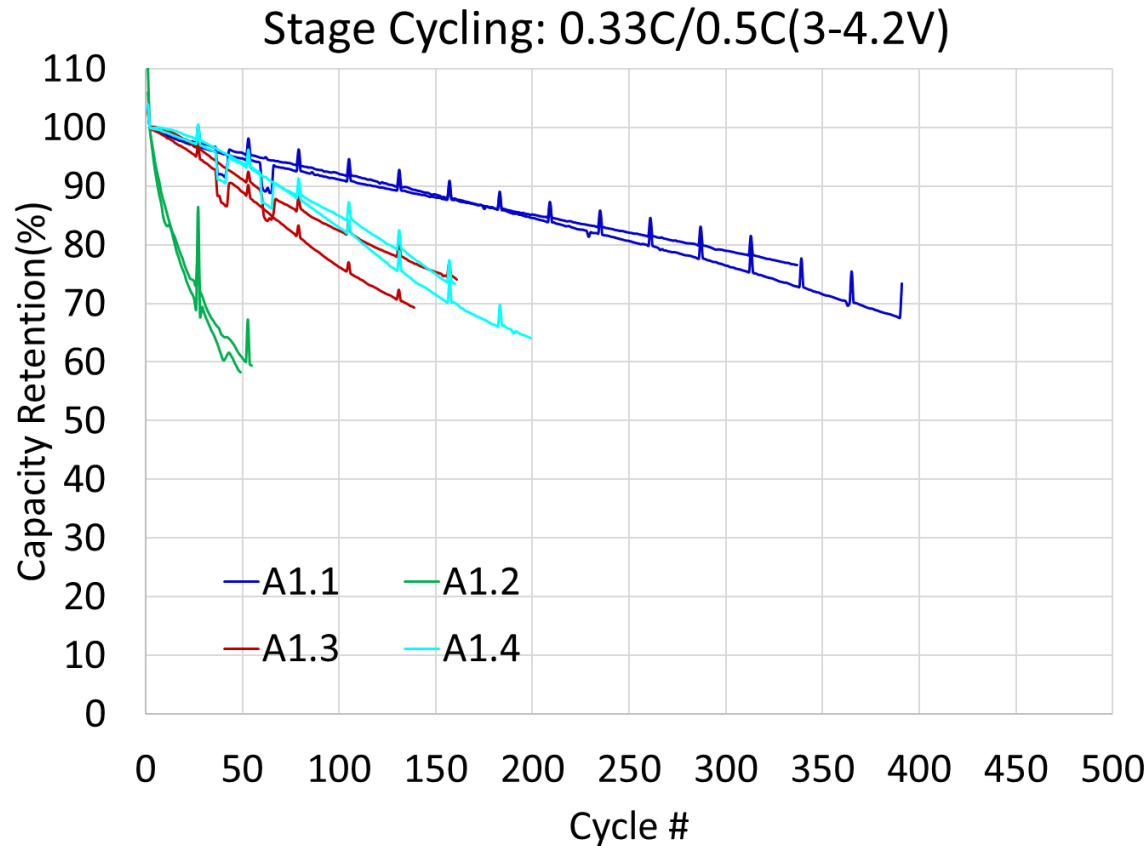
- Ni rich cathode have better cycle life as compared to other higher voltage cathode materials (2.5-4.5V). May be the electrolyte optimization can help to improve the cycle life.
- The lower voltage is stressing the Si material where as the higher voltage leads to the oxidative degradation of the electrolyte .
- C1.6 is non-coated cathode, which leads to poor cycle life at high voltage.
- Cycle life @ 80% retention is 350 Cycles



Technical Accomplishments

(A1) Negative Electrode Technology Development

- Evaluated **C1.1 (Ni rich NCM)** with four different type of Si anode in a single layer pouch cells (at fixed anode capacity, same cathode & targeting 330Wh/kg): Cycle life



- Cycle life for the A1.1 is better as compared to other Si materials
 - It can be due to the inactive matrix, which dilute the volume expansion in the electrode as compared to the other Si materials.
 - Cycle life of other materials can be improved by the optimization of the electrolyte, which form a stable SEI layer on anode
- Cycle life @ 80% retention is 350 Cycles

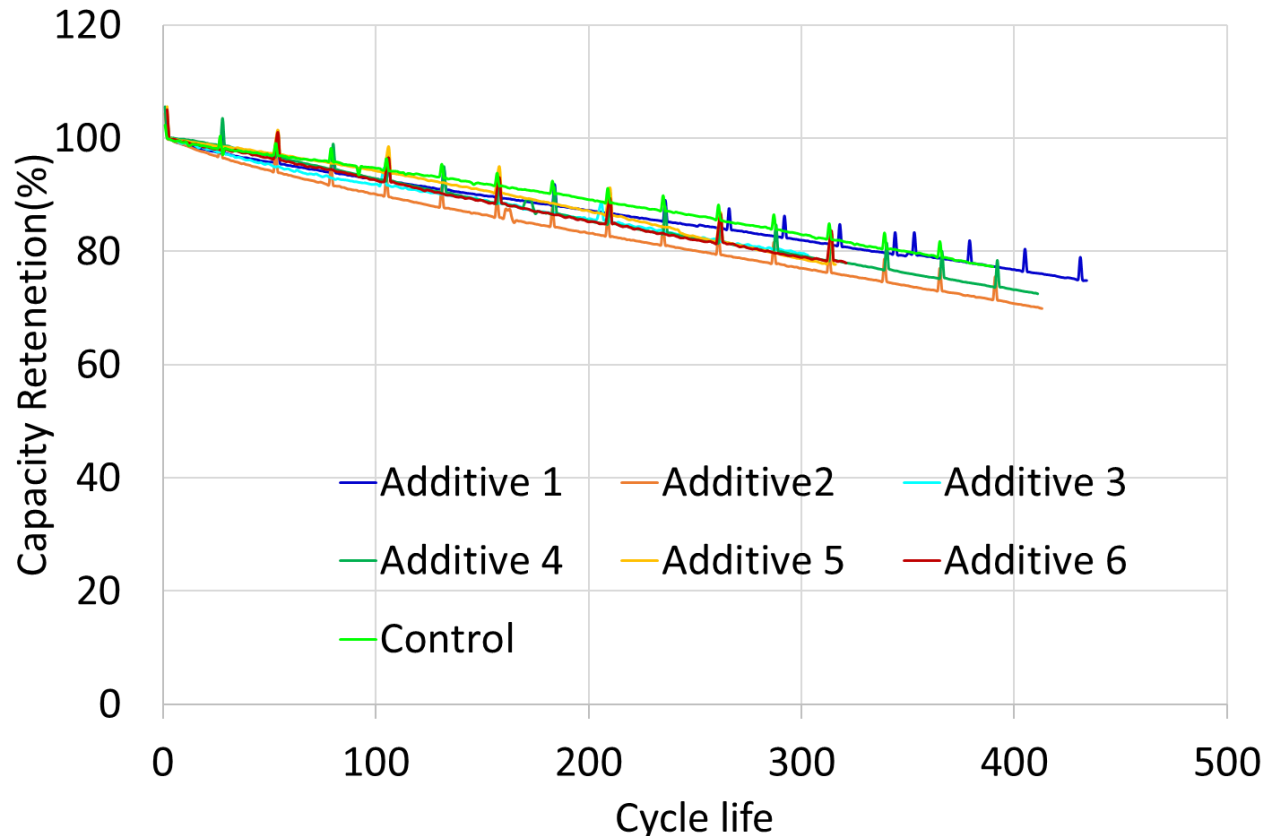


Technical Accomplishments

(A1.1) Negative Electrode Technology Optimization

- Evaluated **C1.1 (Ni rich NCM)** with Si anode(A1.1) with different conductive additive in a single layer pouch cells (at fixed anode capacity, same cathode & targeting 330 Wh/kg):
Cycle life

Cycling: 0.33C/0.5C CV C/20(3-4.2V)



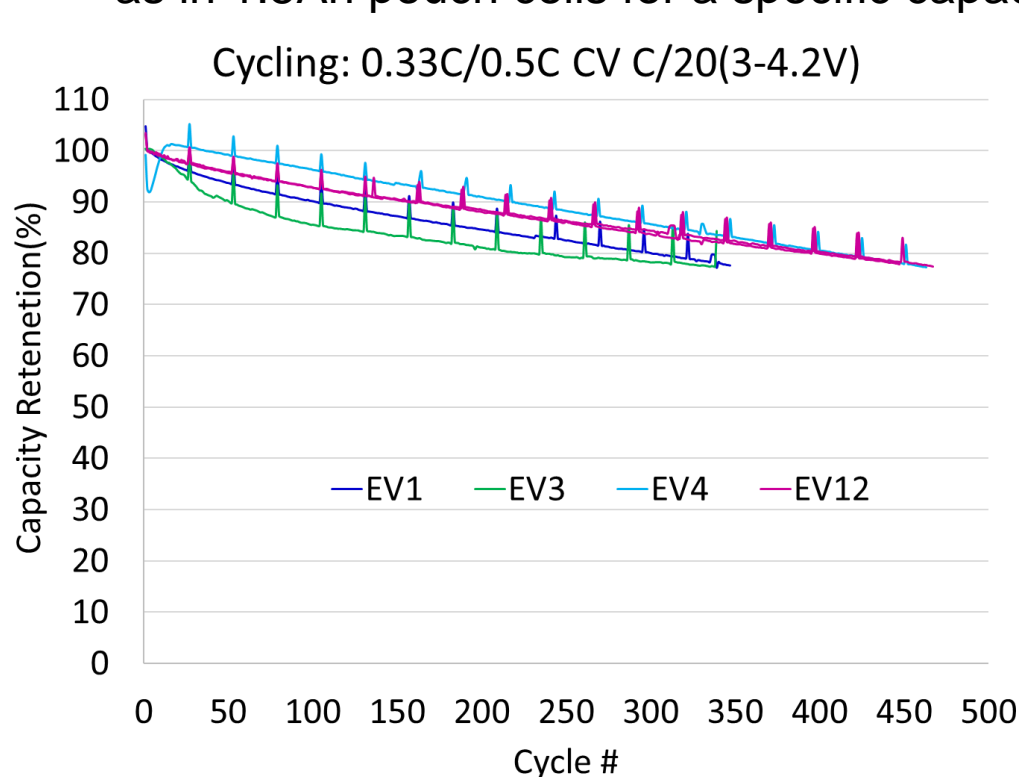
- Cycle life for additive 1 is better as compared to the other additive
- Cycle life @ 80% retention at C/5 for additive 1 is 450 Cycles.



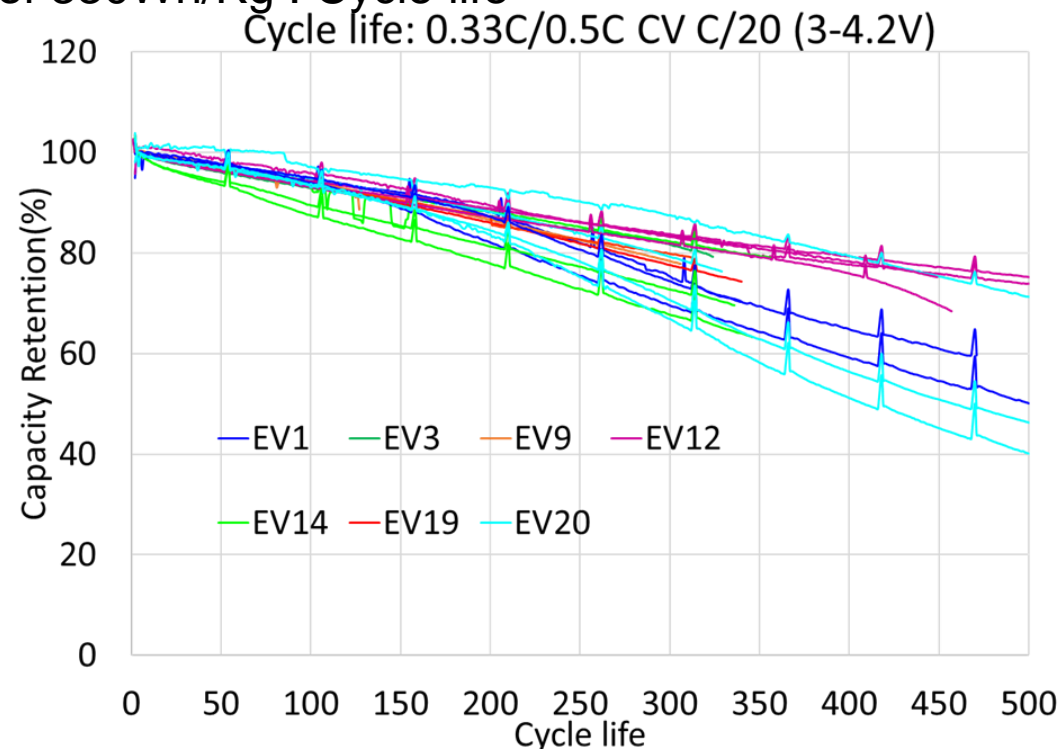
Technical Accomplishments

(E2) Electrolyte Development

- Evaluated of **C1.1 (Ni rich NCM)** with 21 different electrolyte in a Double layer pouch as well as in 1.5Ah pouch cells for a specific capacity of 330Wh/Kg : Cycle life



Double Layer Pouch Cells



1.5 Ah Pouch Cells

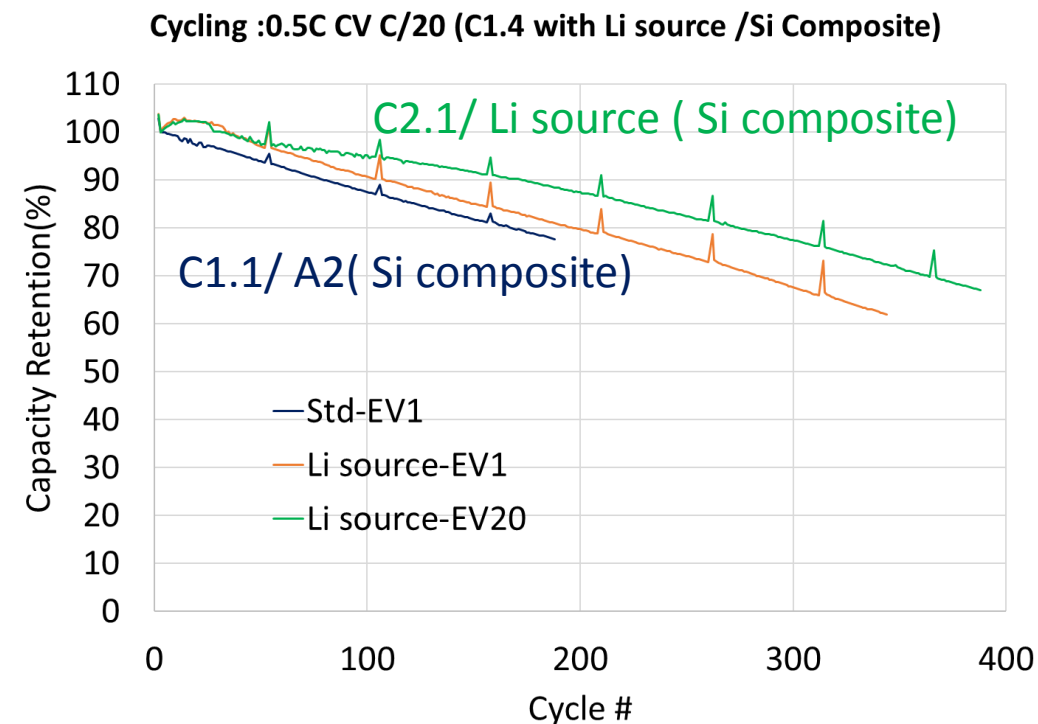
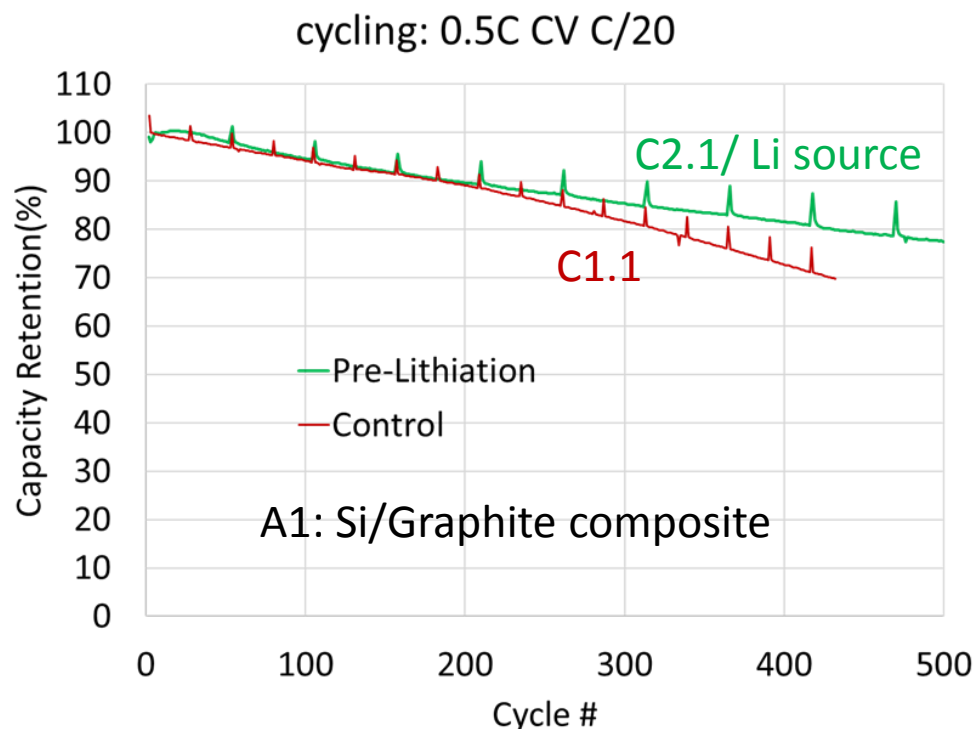
- More than 20 cells are build with EV12 and the results are reproducible for this electrolyte. DCIR is low and rate capability is higher as compared to other electrolyte. The cycle life @ 80% retention for EV12 is 450-500 cycles.



Technical Accomplishments

Cell Development with Li Source

- Comparison of cycle life of Ni rich NCM with sacrificial Li source



- C2(~187mAh/g) Cathode with A1 Silicon graphite composite anode targeting 330Wh/Kg**
- Impedance of pre-lithiated cells are higher as compared to control cells
- Pre-lithiation help to improve the capacity retention
- C2 (Cathode with Li source) & A2(Si composite) anode targeting 360-375Wh/Kg**
- Cycle life for the cells with Li source is higher as compared to the control cells



Technical Accomplishments

Summary Cell Development: Gen1 (300Wh/Kg)

- **C1: Cathode evaluation for the 1st generation deliverable**
 - Evaluated 12 (of 13) different cathode materials in a single layered pouch cell (at fixed capacity targeting ~ 300-330 Wh/kg) and cathode capacity of ≥ 185 -210mAh/g
 - Ni rich NCM is one of the candidate for the further optimization because of high capacity, lower impedance, better rate capability and cycle life
 - Cathode with capacity > 195mAh/g with lower DCIR and higher cycle life will go further optimization of the formulation
- **A1: Anode evaluation for the 1st generation deliverable**
 - Evaluated four (of 4 planned) different anode materials in a single layered pouch cell (at fixed capacity targeting ~ 300-320 Wh/kg) for Si/ graphite composite
 - A1.1 further go on optimization because of low impedance, higher rate and better cycle life as compared to other Si materials
- Build is on progress for making ~ 1.5Ah(100 Dry cells) for electrolyte optimization and safety testing from down selected chemistry of C1 & A1



Responses to Previous Year Reviewers' Comments

- **This project is a new start**

Collaboration and Coordination with Other Institutions

- **Argonne National Laboratory (Chris Johnson):**

Federal Laboratory – Subcontractor helping to stabilize the materials and analytical work for project.

- **Sacrificial Li-Source Development**

- Argonne National Laboratory and Farasis have develop the sacrificial Li- Source under a previous SBIR funded project. In collaboration with Argonne National Lab we will try to optimize the chemical composition of the materials for air stability.

- **Lawrence Berkeley National Laboratory (Robert Kostecki):**

Federal Laboratory – Subcontractor providing high voltage conductive additive for project.

- **High Voltage Stable Conductive Additive**

- Robert Kostecki at Lawrence Berkeley National Laboratory has developed surface modified carbon blacks and nanofibers that can help to improved stability at high potentials (>4.4V)

Remaining Challenges and Barriers

- Stability of Copper foil for higher amount of Si
- Stabilization of the Li –source to make it compatible with the manufacturing
 - Farasis and Argonne National Lab is working on the coating of the Li source to improve the air stability of the material
- Understand the effect of the Li source on the impedance of the cell
 - Initial results shows the addition of Li source increase the impedance of the cell. Working on the characterization of the cell and understanding the source of contribution of the impedance of the cell.

Proposed Future Research

- Deliver Gen1 Cell

- Specific Energy ~ 300Wh/Kg
- Energy Density ~ 625Wh/L
- Cycle life > 500 Cycles
- Safety Testing on Gen1 Cells

- Gen 2 Development

- C3: Cathode development with capacity of higher than 200 mAh/g with Li source
- Stability of the Li source
- A3: Si composite with capacity higher than 1500mAh/g
- Electrolyte optimization for the Gen2 Cell design
- Safety testing

Summary Slide

- Baseline Cells deliver to National Lab
- Evaluated 12 cathode material with capacity higher than 187mAh/g at different voltage
- Evaluated 4 anode material with capacity in-between 400-1800mAh/g
- Based on these evaluation down-selected anode(A1) and cathode (C1) for the Gen1 deliverable
- Improvement in the cycle life, capacity, impedance and rate capability is achieved by optimization of anode and electrolyte
- Initial builds are done for cathode with Li source and Si composite anode. Started the investigation on the impact of Li source on cycle life, capacity and impedance of the Cell

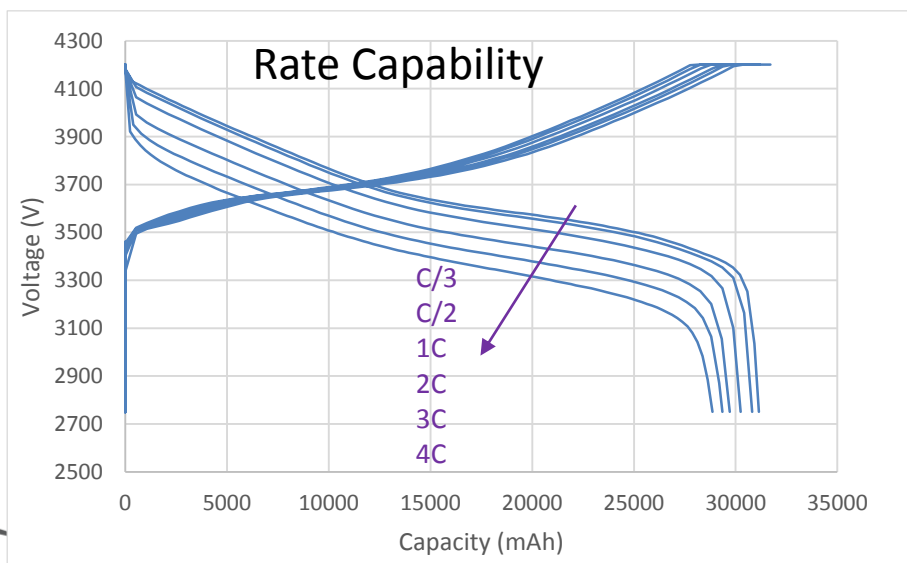
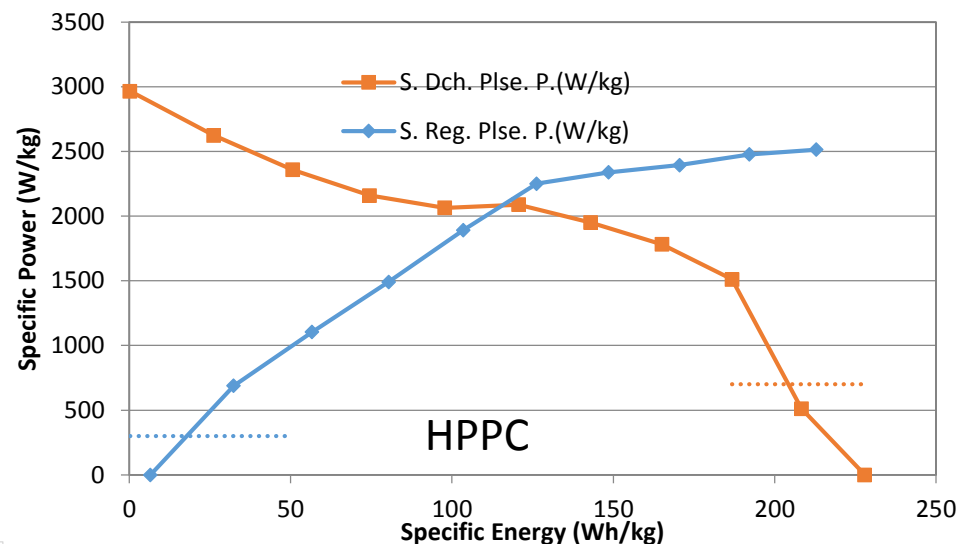
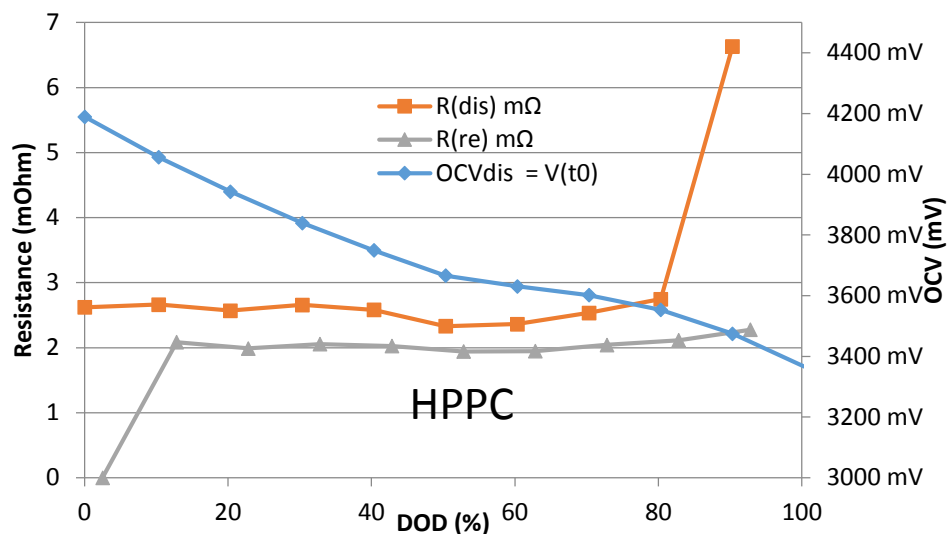


Technical Back-Up Slides



Technical Accomplishments

Cell Development: Baseline Cell Performance - DCR, Power, Rate



- Test Temperature: 30°C
- HPPC
 - Discharge pulse: 30s, 92A
 - Charge pulse: 10s, 69A
 - V_{max} : 4.2V
 - V_{min} : 2.75V
- Rate
 - Charge at C/3 to 4.2V, CV till C/50
 - Discharge to 2.75V at various C-rates